Technical Publication TP-72-24

EFFECTS OF TARGET SIZE, TARGET CONTRAST, VIEWING DISTANCE, AND SCAN LINE ORIENTATION ON DYNAMIC TELEVISUAL TARGET DETECTION AND IDENTIFICATION

(AIRTASK A340 5313/225-B/2F00524001)

By

R. A. BRUNS, A. C. BITTNER, JR., and
R. C. STEVENSON
Systems Integration Division

17 August 1972

APPROVED FOR PUBLIC RELEASE; DISTRIBUTION UNLIMITED.

NAVAL MISSILE CENTER

Point Mugu, California

TP-72-24 (U)

NAVAL MISSILE CENTER

AN ACTIVITY OF THE NAVAL AIR SYSTEMS COMMAND

E. E. IRISH, CAPT USN
Commanding Officer

This report describes work accomplished under AIRTASK A340 5313/225-B/2F00524001, Aircrew Human Factors Engineering.

CDR W. H. Nelson, Head, Human Factors Engineering Branch; Mr. E. P. Olsen, Head, Systems Integration Division; and Mr. J. J. O'Brien, Associate Laboratory Officer, have reviewed this report for publication.

ACCESSION for		
NTIS	White Section	☑
DDC	Buff Section	☐
UNANNOUNCED		☐
JUSTIFICATION		
BY		
DISTRIBUTION/AVAILABILITY CODES		
DIST.	AVAIL. and/or SPECIAL	
A		

Technical Publication TP-72-24

Published by . . . . Editorial Branch
Technical Publications Division
Photo/Graphics Department
Security classification . . . . UNCLASSIFIED
First printing . . . . 200 copies

UNCLASSIFIED
Security Classification

DOCUMENT CONTROL DATA - R & D

Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author) Naval Missile Center Point Mugu, California 93042	2a. REPORT SECURITY CLASSIFICATION UNCLASSIFIED 2b. GROUP

3. REPORT TITLE

EFFECTS OF TARGET SIZE, TARGET CONTRAST, VIEWING DISTANCE, AND SCAN LINE ORIENTATION ON DYNAMIC TELEVISUAL TARGET DETECTION AND IDENTIFICATION

4. DESCRIPTIVE NOTES (Type of report and inclusive dates)

5. AUTHOR(S) (First name, middle initial, last name)

R. A. Bruns, A. C. Bittner, Jr., and R. C. Stevenson

6. REPORT DATE	7a. TOTAL NO OF PAGES	7b. NO OF REFS
17 August 1972	34	19

8a. CONTRACT OR GRANT NO b. PROJECT NO. AIRTASK A340 5313/225-B/ 2F00524001 c. d.	9a. ORIGINATOR'S REPORT NUMBER(S) TP-72-24 9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)

10. DISTRIBUTION STATEMENT

Approved for public release; distribution unlimited.

11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY
	Naval Air Systems Command

13. ABSTRACT

This report describes a simulation research study which measured the effects of (1) target size, (2) target-to-background contrast, (3) television raster scan line orientation, and (4) display viewing angle on both target detection and target identification using television. One hundred twenty different simulated air-to-surface target "attacks" against buildings on a three-dimensional terrain model were video tape-recorded using a 525-line television system. These attacks were then shown to 16 subjects whose tasks were to detect the target from its background and to identify it from a number of alternatives shown on briefing photographs. Performance measures were (1) slant range at correct detection (SRD), (2) slant range at identification (SRI), and (3) probability of correct identification (PCI). ( )

Major conclusions reached were as follows:

1. Target effects were of major importance across all three criteria but were comparatively the most important for PCI. Target effects were found to be primarily related to target size expressed either as target area or target diagonal.
2. Target contrast was by far the most important variable investigated for SRD. It was also of major importance for SRI and was of moderate importance for PCI. Increased target contrast resulted in increased subject performance across all three criteria.
3. Vertical raster scan line orientation was statistically superior (11 percent greater slant range) to horizontal raster scan line orientation for the SRD criterion only, but the differences were in the same direction for all three criteria.
4. The different display viewing angles used in the study had no significant effect on any of the three criteria although the outcome for the detection task may have been dependent upon the task structure employed.
5. Subjects differences were of substantial importance for all three criteria but were comparatively the most important for SRI.

Continued

DD FORM 1 NOV 65 1473 (PAGE 1)
S/N 0101-807-6801

UNCLASSIFIED
Security Classification

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Human factors engineering						
Target detection						
Target identification						
Visual acuity through television						

13. Concluded.

6. None of the independent variables interacted significantly for any of the three criteria.

Based on the results of this study, it is recommended that further research focus on (1) techniques for contrast image enhancement, (2) verification of the superiority of vertical versus horizontal scan line orientation, and (3) delineation of the effects of display viewing angle upon a target detection task requiring search across the entire television display.

ACKNOWLEDGMENTS

The authors wish to express their thanks to the 16 people who served as subjects in this experiment. A special debt of gratitude is owed to Mr. Dale Mahar and Mr. Ron Baldwin for building the response apparatus and for assisting in the data collection. Additionally, we wish to thank Mr. John Stroud for his assistance with the computer programs. Finally, we wish to thank Mrs. Pat Motley for typing this manuscript.

CONTENTS

CONTENTS (Concluded)

TP-72-24
17 August 1972

NAVAL MISSILE CENTER

Point Mugu, California

EFFECTS OF TARGET SIZE, TARGET CONTRAST, VIEWING DISTANCE, AND SCAN LINE ORIENTATION ON DYNAMIC TELEVISUAL TARGET DETECTION AND IDENTIFICATION (AIRTASK A340 5313/225-B/2F00524001)

By

R. A. BRUNS, A. C. BITTNER, JR., and
R. C. STEVENSON

SUMMARY

This report describes a simulation research study which measured the effects of (1) target size, (2) target-to-background contrast, (3) television raster scan line orientation, and (4) display viewing angle on both target detection and target identification using television. One hundred twenty different simulated air-to-surface target "attacks" against buildings on a three-dimensional terrain model were video tape-recorded using a 525-line television system. These attacks were then shown to 16 subjects whose tasks were both to detect the target from its background, and to identify it from a number of alternatives shown on briefing photographs. Performance measures were (1) slant range at correct detection (SRD), (2) slant range at identification (SRI), and (3) probability of correct identification (PCI).

Major conclusions reached were as follows:

1. Target effects were of major importance across all three criteria but were comparatively the most important for PCI. Target effects were found to be primarily related to target size expressed either as target area or target diagonal.

2. Target contrast was by far the most important variable investigated for SRD. It was also of major importance for SRI and was of moderate importance for PCI. Increased target contrast resulted in increased subject performance across all three criteria.

3. Vertical raster scan line orientation was statistically superior (11 percent greater slant range) to horizontal raster scan line orientation for the SRD criterion only, but the differences were in the same direction for all three criteria.

4. The different display viewing angles used in the study had no significant effect on any of the three criteria although the outcome for the detection task may have been dependent upon the task structure employed.

5. Subjects' differences were of substantial importance for all three criteria but were comparatively the most important for SRI.

6. None of the independent variables interacted significantly for any of the three criteria.

Based on the results of this study it is recommended that further research focus on (1) techniques for contrast image enhancement, (2) verification of the superiority of vertical versus horizontal scan line orientation, and (3) delineation of the effects of display viewing angle upon a target detection task requiring search across the entire television display.

Publication Unclassified.

GLOSSARY

B	Block
C	Contrast
df	Degrees of freedom
DVA	Display viewing angle
DVA*C	Display viewing angle and contrast interaction
DVA*SLO	Display viewing angle and scan line orientation interaction
DVA*T	Display viewing angle and target interaction
DVA*T*C	Display viewing angle, target, and contrast interaction
EMS	Error mean square
F	F-ratio
MS	Mean square
p	Probability
PCI	Probability of correct identification
PTA	Perspective target area
PTD	Perspective target diagonal
r^2	Pearson product-moment correlation squared
S	Subject
SLO	Scan line orientation
SRD	Slant range detection
SRI	Slant range identification
SS	Sum of squares
T	Targets
T*C	Target and contrast interaction
T*SLO	Target and scan line orientation interaction

INTRODUCTION

Within the past few years, closed-circuit TV (television) systems have come into operational use in military aircraft. New developments in sensor technology have multiplied the potential applications of television to military tasks. For example, the development of the image orthicon camera enable. low light level television to function on a moonless night with heavy cloud cover (10^{-5} footcandles) while human eyes reach their limit of useful vision at about a quarter moon (10^{-3} footcandles) (Zachary, 1967) (reference 1). Contrast sensitivity of television cameras has been developed to the extent that it is possible to build tracking circuits which exceed the ability of the television monitor to display the object being tracked.

The consequence of these developments is that military airborne television systems are becoming increasingly display-limited. Since these displays are being viewed by human operators, the display and the display viewing environment must be designed to take maximum advantage of the operator's perceptual capabilities while compensating for his limitations if full system effectiveness is to be realized.

The current airborne television display design objective is to maximize the accuracy and distance at which objects on the ground can be "found." "Finding" an object of interest is a three-part process consisting of *detection*, *recognition*, and *identification*–in that order (Armed Force NCR Committee on Vision, 1968) (reference 2). *Detection* is the process of isolating an object of interest from the background (e.g., "I see something that might be what I'm looking for.") Operationally defined, detection occurs when the observer commits himself (by changing course for example) to regard a particular object in his field of view as the target. *Recognition* consists of perceiving specific object features in sufficient detail to assign the object detected to a class of things (e.g., "What I see is a tank."). *Identification* consists of perceiving object features in sufficient detail to assign the object to a specific subset of the class of objects (e.g., "What I see is a friendly Sherman tank."). In much of the electro-optical system literature, object recognition is not separated from object identification; instead object identification is used to refer to both processes. That convention will be followed throughout this report.

There are five factors, each with a number of dimensions and interactions, which affect the ability of an airborne operator, using television, to detect and identify an object. These factors are: (1) target, (2) environment, (3) sensor, (4) display, and (5) observer. The order in which these factors are listed corresponds to the sequence with which they interface with each

Preceding page blank

other. Light reflected from the target is transmitted through the environment to the television sensor. The TV camera in turn relays the image to a display where it is perceived, interpreted, and acted upon by a human observer. It is pointless to debate which of these factors is the most important. Sufficient degradation in any one of them will result in system failure. What is important is determining exactly how changes in each of these factors affect system performance. This information can then be paired with cost data to develop cost/benefits ratios which can be applied to future system development.

In a previous study (Bruns et al, 1970) (reference 3) Bruns investigated the effects of TV display size, TV viewing distance, and certain target characteristics upon target identification performance. It was found that 3 1/2, 5-, and 8-inch-diagonal-size monitors provide equivalent performance across a wide range of viewing distances. However, due to the nature of the briefing procedure, it was not possible to measure target detection performance. Subjects were shown reconnaissance photographs and then asked to identify on TV a target marked on the photograph. There were sufficient background cues on the photograph for the subjects to determine exactly where on the display the target would appear. Therefore, no search was involved, and it is not surprising that the display angular subtense presented made little difference. (Display angular subtense is the angle formed by lines drawn from the midpoint between the observer's eyes to the top and bottom of the TV display. It is thus jointly determined by display size and display viewing distance.)

Enoch (1959) (reference 4) found that a display angular subtense of 9 degrees was optimum in terms of efficiency of eye-fixation patterns when the task was to search aerial maps for certain features In order to determine whether this finding is also true for detecting ground targets from the air, display angular subtense was included as a variable in this study for both target detection and identification.

A number of researchers have found that two conditions must be met before objects can be identified on television. (Shurtleff et al, 1966, reference 5; Baker and Nicholson, 1967, reference 6; Hemingway and Erickson, 1969, reference 7). First, the object must be a minimal size in terms of angular subtense at the eye of the observer. Second, a minimal number of television raster scan lines must cross the object. The term "raster scan lines" refers to the way in which information is displayed on a television monitor. The face of the monitor (raster) is composed of a number (525 for American broadcast television) of evenly spaced horizontal lines separated by blank spaces. Information is written on these lines by the cathode-ray tube scanning spot which sweeps each line at regular intervals, changing the brightness of the individual phosphor elements which comprise the line. These variations in brightness result from variations in light intensity reflected by the target as seen by the television camera.

Both the number of scan lines crossing the object and the object angular subtense required for good identification performance are highly task-dependent. Shurtleff (1967) (reference 8) found that alphanumeric symbols could be identified with 98 percent accuracy when there were ten lines per image height and the image subtended 14 minutes of arc. Under the same scan line and image size conditions, Erickson and Hemingway (1970) (reference 9) found that only about 84 percent of the military vehicles presented could be correctly identified. The vehicles were photographed against a homogeneous terrain background, and then were statically presented to the viewer by scanning the photographs with a TV camera. Using actual targets in their natural surrounding and a dynamic viewing presentation (reconnaissance transparencies projected to simulate range closure), Bruns et al (1970) (reference 3) obtained only about 63 percent correct target identification.

The implication of these findings to research is clear. Laboratory research must incorporate a task structure which is similar to the environment to which the results are to be generalized. If an airborne television display is to be used to detect and identify targets in a complex visual environment, then this environment should be simulated as accurately as possible in the research situation.

Because the number of scan lines crossing the target is one of the factors limiting target identification, it is worthwhile to explore methods of increasing this number. There is evidence to indicate that some gain can be achieved by increasing television scan line rate. Hemingway and Erickson (1968) (reference 10) found that some information could be transmitted by scan lines as small as 0.25 minute of arc. Scan line structure was still visible to observers with 20/12 visual acuity at that size. This corresponds to 2,500 scan lines on a 4-inch raster viewed at 18 inches. Visual target recognition was investigated by Bennett (1967) (reference 11) who found that up to a point, higher resolution improves the "coding" of the display information. However, there is a limit beyond which increases in resolution do not further improve performance.

Despite Erickson's success in demonstrating that high line rates should have additional information transmission capabilities, his comparison (1967) (reference 12) of symbol legibility between 525- and 875-line systems showed little difference. Similar results were found by Shurtleff (1966) (reference 13) who compared symbol legibility on 525- and 945-line systems. Again, no experimental data exists for relating these results to the identification of targets in an operational environment.

One means of increasing the number of scan lines crossing the horizontally elongated target without increasing the line rate of the system would be to orient the scan lines vertically. This can be accomplished by rotating the television monitor deflection yoke 90 degrees. Orienting the scan lines vertically will result in more scan lines across the target because most tactical missile targets present a greater width than height dimension on the airborne TV display. There are two causes for this phenomena. First, the oblique angle from which targets are seen results in foreshortening of the height demension. Second, attacking aircraft would normally select a broadside heading to the target (e.g., a bridge) which would maximize the apparent target area on the display. The authors know of no previous target detection and identification research in which scan line orientation was a variable: therefore, it was included in the experimental design as a variable.

Another finding of the Bruns et al (1970) (reference 3) study was that next to target size, target contrast is the most important target characteristic for target identification. Contrast enhancement techniques are available which can be used to "boost" target contrast, but at some cost in display quality. Exactly how much target contrast is needed for good target identification performance could not be determined from the previous study so target contrast was included as a continuous variable in the present study.

METHOD

Subjects

The subjects were 16 military and civilian personnel from the Pacific Missile Range and Naval Missile Center commands at Point Mugu, California. All had uncorrected or corrected near binocular visual acuity of 20/20 or better.

Equipment

Targets

Five different target shapes, shown in figure 1, were used in the study. The targets were constructed to a 2,000-to-1 scale and the physical dimensions were 3/16 inch high and 1/2 inch wide, and were 1 1/2, 1, or 1/2 inch long, respectively, for targets 1, 2, and 3 in figure 1. Targets 4 and 5 are target shapes 1 and 2 rotated 90 degrees. Table 1 contains the scaled sizes of the targets. The "apparent size" is the result of viewing the targets on TV at a 30-degree oblique angle from the air. Two sets of five targets were used in the study. One set was painted a lighter color than the other, but all targets within a set were painted the same. On all targets the sides were made lighter than the top to provide a homogeneous contrast from the background when viewed on the terrain model through the TV system.

Terrain Model

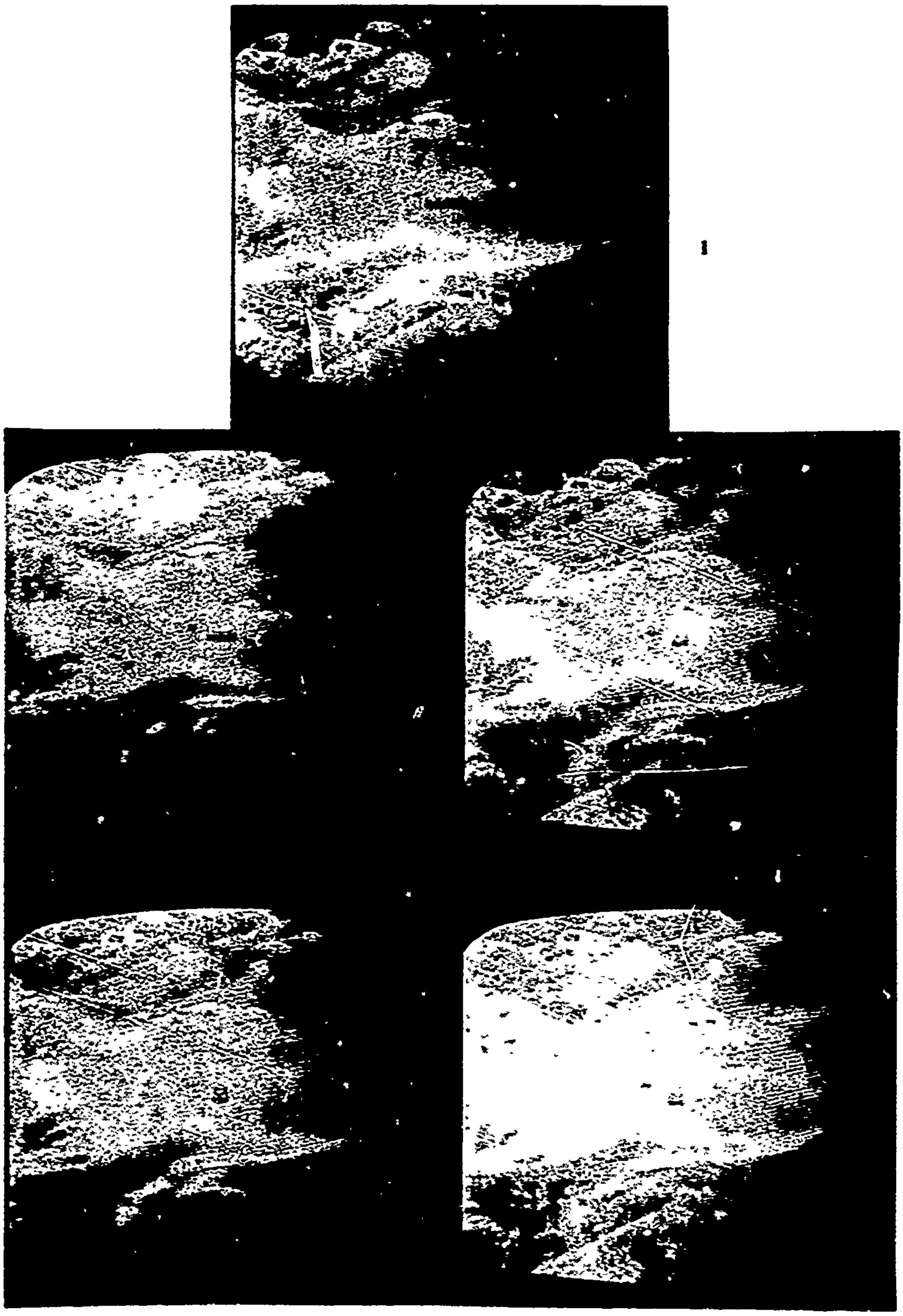
Background for the targets was a 2,000-to-1-scale, three-dimensional terrain model, 4 miles wide and 4 1/2 miles long. The terrain was uninhabited, gently rolling grassland dotted with scattered brush and trees. No roads or man-made features were present on the terrain except for the targets. Figure 2 is a photograph of the model. The lines visible in the picture are the edges of 16 inch-square modules which make up the terrain. The mountain shown in the rear of the photograph was replaced by terrain similar to that in the foreground during the experiment. The sides of the terrain model are covered with polished steel which forms a reflective surface and provides continuity at the edges of the model.

It was planned to achieve specified levels of contrast (5 percent, 10 percent, etc.) but this proved to be extremely difficult for two reasons. First, present lighting for the terrain model is provided by overhead fluorescent lights. Because of the inverse square law, these lights provide more light at the center of the model than at the edges. Fill-in lights were ordered, but did not arrive in time to be used in the experiment. The second problem encountered was that movement of the gantry containing the TV camera blocked off an increasing amount of light as the gantry moved closer to the target location.

In response to these problems, target contrast was made a continuous variable. Eight different locations were selected on the terrain model for target placement. All locations chosen were level ground. Level sites were necessary to retain the same apparent target size at all sites. No trees were present within 200 feet of the center of each site. Site brightness was uniform within 2 percent within a radius of at least 200 feet of the site center. A Spectra Prichard photometer was used to obtain brightness readings from the face of the TV display used in the study under the same ambient lighting conditions (10 footlamberts) employed when experimental data were collected. Percent contrast was then calculated using the following formula:

$$\text{Percent contrast} = \frac{|\,\text{Brightness target} - \text{Brightness background}\,| \times 100}{\text{Brightness Background}}$$

The use of this formula for calculating contrast always results in positive contrast values with a possible range from 0 to infinity. It also has the advantage of yielding equal values for targets that are an equal amount brighter or darker than their background. The percent contrast range investigated in this study was from 3 percent to 76 percent. Target backgrounds used were lighter than the target 60 percent of the time and were darker 40 percent of the time.



1 2 3 4 5

Figure 1. Five Target Shapes as They Appeared on the Television Monitor.

Table 1. Three-Dimensional Target Sizes Reduced to Two Dimensions on Television

Target	Actual Size (Feet)			Apparent Size* (Feet)		Apparent Size Aspect Ratio (Length to Height)
	Length	Width	Height	Length	Height	
1	250	83	31	250	73	3.42 to 1
2	166	83	31	166	73	2.27 to 1
3	83	83	31	83	73	1.14 to 1
4	83	166	31	83	115	1 to 1.39
5	83	250	31	83	156	1 to 1.88

*Results from viewing target on television at a 30-degree oblique angle from the air.

Figure 2. Terrain Model.

Test Material

Simulated air-to-surface target attacks were then video tape-recorded against all factorial combinations of target locations (8); target shapes (5); target coloration (2); and scan line orientation (2)–for a total of 160 sorties. To overcome the problem of varying contrast as a function

of gantry location, gantry position was fixed and a Zoomar 10-to-1 variable speed zoom lens was used instead to simulate range closure. All attack parameters except aircraft velocity were the same for all 160 sorties. Attacks began at an altitude of 27,500 feet and ended at 2,750 feet. A 30-degree dive angle was maintained which resulted in an initial slant range of 55,000 feet and a terminal slant range of 5,500 feet. Aircraft velocity was constant within each sortie, but varied from 250 knots to 315 knots across sorties with a mean of 275 knots. The velocities varied randomly across sorties because it was difficult to repeatedly achieve exactly the same voltage output from the rheostat regulating power to the zoom lens drive motors.

A General Electric model TE-9 8-megahertz, 525-line television camera provided the video imagery. The camera was operated at a constant gain setting by substituting an external reference voltage in place of the automatic gain control. The simulated target attacks were recorded on a Sony model 120A 3.5-megahertz video tape-recorder.

Each simulated target attack recorded was divided into three phases:

Phase 1. All 160 sorties began with the missile hovering for 30 seconds at an altitude of 27,500 feet at the same geographic position in space. The missile and camera were inclined in a 30-degree dive and were positioned so that the camera was pointed at the approximate center of the terrain to be searched.

Phase 2. The missile dove toward the center of the terrain area for 30 seconds at about 275 knots. Only one building was on the terrain at a time, and the building was within the field of view at all times. No other man-made objects were present on the terrain.

Phase 3. After the above minute had elapsed, the missile was instantaneously repositioned back to 27,500 feet and to the geographic position in space which resulted in the TV camera being almost boresighted on the target location. The target was now located within a 1-inch square in the center of the camera field of view. The simulated target attack continued at an average velocity of 275 knots until the missile reached an altitude of 2,750 feet and a slant range of 5,500 feet.

The simulation procedure adopted was designed to be analogous to two situations that might be encountered while guiding a long-range, remotely controlled, television-equipped, air-to-surface weapon.

Phases 1 and 2 simulate a situation in which the weapon had guided to the general target area using computer-generated midcourse guidance commands. The operator now knows he is in the general target area without knowing exactly where he is relative to the target. It is further assumed the terrain is so homogenous as to not provide any contextual cues as to target location, or that no precise information was available about the targets location relative to fixed landmarks. The provision of phase 1, hover time, was designed to artificially compensate for the search time that would be available to the operator prior to the weapon reaching the altitude and slant range at which the simulation began. It was anticipated that no target identifications and few, if any, target detections would occur in this phase.

Phase 3 assumes the same scenario as above except that the operator knows with certainty that the weapon is guiding directly toward the target location. His objective is still to detect and identify the exact target location as soon as possible in order to lock-on to the target. The

simulation procedure adopted also overcomes an otherwise difficult problem in research methodology. The problem is to ensure that all subjects have an equal opportunity to detect and identify the target. If subjects are allowed to fly around the model looking for the target, the target might be outside the TV field of view much of the time, thereby yielding excessively short slant ranges when detected. Similarly, if simulated target attacks were boresighted on the center of the model throughout the attack, targets closer to the center of the model would have a higher probability of remaining in the picture longer than would those on the edge of the model. If the camera were moved to keep the target in the picture, this movement would provide a cue as to target location.

Presentation and Response Recording Apparatus

Simulated target attacks were presented to the subjects on two CONRAC CNB8 8-inch television monitors which were converted from a 5.4-by-7-inch to a 5.4-by-5.4-inch raster by masking off part of the raster. One of the monitors had the conventional horizontal scan line orientation; on the other, the yoke was deflected 90 degrees to present a vertical scan line orientation. Masking was necessary because rotating the raster 90 degrees results in blank areas on the left and right edges of the display. The displays were adjusted to obtain matched video appearance.

Brightness, resolution, and gray step readings were obtained from the playback of video tape-recorded RETMA chart using the same television equipment used in the study. Display brightness varied less than 5 percent between monitors as measured with a Spectra Prichard photometer. Center and corner resolutions were determined by visually observing the number of resolution grid lines that could be separately distinguished. The number of logarithmic gray steps distinguishable was visually determined for each of the four patterns on the RETMA chart and then averaged. Table 2 describes these display characteristics.

Table 2. Television Monitor Display Characteristics

Note: Display brightness varied less than 5 percent between monitors.

Picture Quality	Distinguishable Resolution Lines		Distinguishable Gray Steps
	Center	Corners	
Parallel to scan lines	375	350	9
Perpendicular to scan lines	350	325	9

The subject viewing area was a semidarkened room with ambient illumination of about 10 footlamberts. The display being viewed was mounted on a table at eye level when the subject was seated. Subject-to-monitor viewing distance was controlled by having the subject rest his forehead against a padded bar. The monitor was then moved to achieve the desired viewing distance. Seating height was controlled with an adjustable chair. Figure 3 shows the subject's viewing station, and figure 4, the expermenter's control station.

Figure 3. Subject's Viewing Station.

Two Sony model 120A 3.5-megahertz video tape-recorders were used to play back the target attacks which were recorded on nine video tapes. Two recorders were used to reduce the intertrial delay since the next attack presented could be on any of the tapes. A 14-inch monitor was used to observe the material being presented to the subject, and a 3½-inch monitor was used to cue up the starting point of the next attack to be presented to the subject.

The units of data recorded by the experimenter were (1) the times from the start of the attack until target detection and identification, (2) whether detection was correct, and (3) what target the subjects identified.

A tone was placed on the audio channel of the video tapes at the start of each simulated attack. This tone, reset to 0, started a Hewlett-Packard model 5212A electronic counter which provided timing data to the nearest tenth of a second. The counter was linked to a Hewlett-Packard model 562A digital recorder which provided a paper readout every time a subject initiated a response. The digital recorder also printed the number of the target selected at target identification. This information was transmitted from the subject's response apparratus through a Newcomb SA-80B amplifier which also displayed a 5-light array used to visually indicate to the experimenter which target had been selected.

Figure 4. Experimenter's Control Station.

PROCEDURE

The subject indicated target detection with a joystick control by placing a crosshair on the target location and then depressing a pushbutton located on the lower left portion of the

response console. The crosshairs were generated with a Raytheon electronic television pointer installed in series with the video line of the television system. The subject indicated target identification by depressing a pushbutton which corresponded to two photographs of the target just above the button. (The upper row of photographs in figure 3 are not the ones used in the study.) Each vertically arranged pair of photographs was identical except that one was taken from the display with horizontal scan lines and the other was taken with vertical scan lines. Only one set of photographs corresponding to the scan line orientation in use was then used as briefing material. The reason for this procedure was that if scan line orientation does make a difference in target detection or identification, then use of only one set of photographs would bias the results.

The suitability of all procedures outlined herein was evaluated by "dry-running" two experimental sessions. Each session was also preceded by five practice runs. Instructions to subjects are contained in the appendix. Printed instructions were given to the subjects, and then the instructions were read aloud by the experimenter.

EXPERIMENTAL DESIGN

Sixteen subjects each observed 40 simulated attacks, for a total of 640 observations. Since the 640 observations were evenly divided across 160 different attacks, as shown in table 3, each attack was replicated 4 times during the experiment. The 40 attacks viewed by each subject were divided into 4 parts of 10 attacks each. The horizontal and vertical scan line monitors were changed after every 10 attacks. Subjects saw an equal number of attacks on each monitor, and the order of monitor usage was balanced every two subjects. Within each group of 10 attacks, 5 were made against the darker targets and 5 were made against the lighter targets. Within these constraints, the order of attack presentation was randomly drawn without replacement. Table 3 illustrates this procedure by showing the first 20 attacks presented to subject one.

Table 3. Matrix of 160 Target Attacks Used in Study.
(Order of presentation for the first 20 attacks presented to subject one.)

Target		Horizontal Scan Line Orientation								Vertical Scan Line Orientation							
		Target Location:								Target Location:							
		1	2	3	4	5	6	7	8	1	2	3	4	5	6	7	8
Darker	1		5					6							17		
	2			3										19			15
	3														14		
	4													12			
	5						4		8								
Lighter	1									13							
	2	7															
	3			9	1												20
	4				10		2									18	
	5										11					16	

Monitor viewing distance was also changed each time scan line orientation was varied. Assignments of viewing distances to the codes a, b, c, and d were randomly determined. The viewing distances selected resulted in display subtended angle heights and widths of 9, 12, 15, and 18 degrees. Each of the four viewing distances was used for every subject. A balanced-for-residual-effects latin square shown in table 4 was developed for every four subjects. Under this arrangement, the order of viewing distances used is balanced across subjects. In the event that any viewing distance carryover effect exists, this effect will be equally distributed across subjects and thus can be partialed out statistically (Cochran, 1957) (reference 14).

Table 4. Sequence of Display Viewing Distances Used With Subjects

Subject	Sequence*
1, 5, 9, 13	a b c d
2, 6, 10, 14	b d a c
3, 7, 11, 15	c a d b
4, 8, 12, 16	d c b a

*Viewing distances: a = 16.6 in., b = 19.9 in., c = 25.0 in., d = 33.4 in.

RESULTS

The analysis of the data was accomplished in three phases: (1) construction of a linear model, (2) least squares fitting and variance partitioning for this model, and (3) analysis of the fitted model.

The Model

Under the model developed for each of the following analyses, each score was thought of as having 14 additive components. These included the seven following "simple components":

Subjects (S)–a component reflecting which of the 16 subjects generated the score

Blocks (B)–a component denoting in which of the four time periods the score was made

Display viewing angle (DVA)–a component denoting under which of the four DVA conditions the score resulted

Targets (T)–a component indicating which of the five target shapes was employed

Contrast (C)–the percent contrast present when the observation was made

Scan line orientation (SLO)–a component reflecting whether the TV lines were vertical or horizontal when the observation was made

Grand average–a component present in all scores

In addition there were six components which were the "logical products" of the simple components. They were labeled as follows: DVA*T; DVA*C; DVA*SLO; T*C; T*SLO; and DVA*T*C. Each of these components denotes that a particular combination of conditions was present when an observation was made. For example, the DVA*T term for an observation indicates both the particular display viewing angle and the target under which the observation was made. These terms are frequently called "interactions"–as they will for the rest of this paper. The last component was termed "error" and reflected the variance associated with a particular observation which was not explained by the model.

Both the least squares fitting and the variance partitioning were accomplished by using a generalized multiple regression analysis computer program, BMD02R, developed at the University of California, Los Angeles (Dixon, 1965) (reference 15). This program, as employed, falls under Overall and Spiegel's (1969) (reference 16) Method 1: "Complete Linear Model Analysis." This program, as applied in the present case, sequentially extracted the effects of various sources of variance and printed the amount of variance contributed by each term independently of all preceding terms.

The order that the terms were removed in the analysis to be presented was the same order that the terms were incorporated in the model: subjects, blocks, display viewing angle, targets, contrast, scan line orientation, and the various interaction effects. Since subjects, blocks, display viewing angle, and targets were designed to be orthogonal to each other, the order of their removal was unimportant. Contrast, however, was effectively a continuous random variable which resulted in extraction order being of interest. This wasn't of practical interest because, as will be seen later, no terms beyond scan line orientation were significant. Subsequent to variance partitioning, the sources were tested for significance. These results were then used to simplify the model to only terms significant in one of the analysis. This means that the weights are those that would have resulted from a simultaneous least squares analysis with only the (simple) subjects, targets, contrast, and scan line orientation terms included.

Once a linear model had been established, a secondary analysis of the resulting terms was accomplished. The goal of this analysis was to describe the results graphically and/or to attempt to explain the results. The nature of the secondary analysis will become clearer when encountered.

Variance Partitioning

The multiple regression analysis just described was applied to three different measures of subject performance: (1) slant range at target detection (SRD); (2) slant range at target identification (SRI); and (3) probability of correct target identification (PCI). Probability of correct target detection was not used as a performance measure because all subjects achieved correct target detection by the end of phase 3. All but six correct target detections and all target identifications occurred during phase 3. There were only four correct detections in phase 1 and two in phase 2, so responses from all three phases were pooled for all analyses. SRI represents the subject's last identification response whether correct or not. There were 87 instances wherein subjects failed to identify a target by the end of phase 3. In these cases subjects were asked to make their best guess, and the slant range at the end of the simulated run, 5,500 feet, was entered as the range of target identification. PCI for these "guesses" was 55.2 percent, which indicates that the choices were far from random. PCI for the complete experiment was 68.8 percent.

Tables 5, 6, and 7 contain summaries of the analysis of SRD, SRI, and PCI, respectively.

Table 5. Analysis of Slant Range at Detection Summary

(NS = nonsignificant)

Source	SS	df	MS	F	p
S	9.47	15	0.631	7.27	<0.005
B	0.60	3	0.200	2.30	NS
DVA	0.59	3	0.197	2.27	NS
T	10.12	4	2.530	29.13	<0.005
C	23.35	1	23.350	268.87	<0.005
SLO	1.22	1	1.220	14.05	<0.005
DVA*T	0.78	12	0.065	0.75	NS
DVA*C	0.61	3	0.203	2.34	NS
DVA*SLO	0.25	3	0.083	0.96	NS
T*C	0.67	4	0.168	1.93	NS
T*SLO	0.72	4	0.180	2.07	NS
DVA*T*C	1.77	12	1.148	1.70	NS
Error	49.85	574	0.087	–	–
Total	100.00	639	–	–	–

Table 6. Analysis of Slant Range at Identification Summary

(NS = nonsignificant)

Source	SS	df	MS	F	p
S	16.38	15	1.092	10.70	<0.005
B	0.20	3	0.067	0.66	NS
DVA	0.42	3	0.140	1.37	NS
T	8.80	4	2.200	21.56	<0.005
C	12.46	1	12.460	122.11	<0.005
SLO	0.01	1	0.010	0.10	NS
DVA*T	1.13	12	0.094	0.92	NS
DVA*C	0.25	3	0.083	0.81	NS
DVA*SLO	0.32	3	0.107	1.05	NS
T*C	0.42	4	0.105	1.03	NS
T*SLO	0.29	4	0.073	0.72	NS
DVA*T*C	0.55	12	0.046	0.45	NS
Error	58.57	574	0.102	–	–
Total	100.00	639	–	–	–

There is a distinct pattern to the three summaries of variance partitioning. The same three simple effects, subjects, targets, and target contrasts, were significant in each analysis at the $p < 0.005$ level except that subject effects were significant at the $p < 0.025$ level for the PCI criterion. Also, in each of the three analyses, none of the interaction terms were found to be significant. The only other effect found significant was scan line orientation which was significant at the $p < 0.005$ level for the SRD criterion. It will be graphically shown later that scan line orientation follows the same directional trend for the SRI and PCI criteria.

Table 7. Analysis of Probability of Correct Identification Summary

(NS = nonsignificant)

Source	SS	df	MS	F	p
S	3.85	15	0.257	1.93	<0.025
B	0.29	3	0.097	0.73	NS
DVA	0.08	3	0.027	0.20	NS
T	10.88	4	2.720	20.47	<0.005
C	2.66	1	2.660	20.01	<0.005
SLO	0.22	1	0.220	1.66	NS
DVA*T	0.09	12	0.008	0.06	NS
DVA*C	0.88	3	0.293	2.20	NS
DVA*SLO	0.09	3	0.030	0.23	NS
T*C	1.14	4	0.285	2.14	NS
T*SLO	0.19	4	0.048	0.36	NS
DVA*T*C	1.34	12	0.112	0.84	NS
Error	76.29	574	0.133	–	–
Total	100.00	639	–	–	–

Table 8 is a comparison of the proportion of variance accounted for by the significant terms in each of the analyses. For the experiment as a whole, no single effect dominates performance. Hence, it is useful to examine the pattern of changes in the comparative importance of factors across criterions. SRD is the most highly predictable of the three criterions, and target contrast accounts for more than twice as much variance as the next factor, targets. Compared to its importance for SRD, target contrast accounts for only about half as much variance for SRI and only one-eighth as much for PCI. Targets is by far the most important factor in predicting PCI, but absolute size of the proportion of variance accounted for by targets is approximately equal for all three criteria. Subject differences are the best predictor of SRI performance and are of considerable importance for predicting SRD and PCI performance as well. In summary then, substantial portions of the variance were explained in each of the three analyses and the dominant source of variance varied with the criterion being examined.

Table 8. Comparison of Proportion of Variance Accounted for Among Criteria

	SRD	SRI	PCI
Subjects	9.5	16.4	3.9
Targets	10.1	8.9	10.9
Contrast	23.4	12.5	2.7
Scan line orientation	1.2	NS	NS
Subtotal	44.2	37.8	17.5
All nonsignificant terms	5.9	3.6	6.2
Total	50.1	41.4	23.7

Examining the three analyses one might suspect that a "single factor" might explain the variance for each of the three criteria. In other words, it might be proposed that the three criteria examined were simple linear transformations of one another. Evidence supporting this contention is shown in table 9 which gives the intercorrelations among SRD, SRI, and PCI.

Table 9. Intercorrelation of SRD, SRI, and PCI Criteria for all 640 Runs

	SRD	SRI	PCI
SRD	1.000	0.569*	0.127*
SRI		1.000	0.173*
PCI			1.000

*Significant $p < 0.05$

Evidence counter to the single factor hypothesis is indicated by the changes in the sizes and relative order of importance of "variance-accounter-for sources" indicated in the preceding paragraph. Also suggestive of differences in the three criteria is the logical argument that the tasks are essentially different. In view of these considerations it is felt that the criteria reflect more than one performance dimension.

The most surprising finding in table 9 is that SRI and PCI are positively correlated. This means that the farther from the target the subject was when he made his identification, the more likely it was to be correct. That outcome is a product of the experimental procedure employed. Recall that on 87 of the 640 runs in the study, no identification was made until after phase 3 had terminated. PCI on these runs was only 55.2% versus 70.9% for the remainder of the runs. Since the minimum slant range simulated (5,500 feet) was assigned to these 87 responses, a substantial amount of positive correlation between SRI and PCI was "built in" to the analysis.

Analysis of the Fitted Model

It was shown in the preceding section that the only effects significant for any of the three criteria were subjects, targets, contrast, and scan line orientation. Each of these terms is graphically examined.

Subjects

Subject differences for all three cirteria are shown in figure 5. These differences were significant at the 0.005 level for SRD and SRI, and at the 0.025 level for PCI. Comparing the results in figure 5, one can note that the graphs of SRD and SRI are similar in shape. Indeed, the subjects who had the largest and smallest SRD (subjects 13 and 1, respectively) also had the largest and smallest average SRI. Other parallels between the two curves are apparent. This suggests that those subject effects which operated in the SRD task also operated in the SRI task.

The graph for PCI is not very similar to either SRD or SRI. However, it is noteworthy that as one goes from left to right, each of the three curves has a generally positive slope. This suggests that some effect was operating which tended to result in improved subject performance across criteria as the experiment progressed. Although no completely satisfactory explanation for this phenomenon has been found, several possibilities exist. Instructions to the subjects were standardized and were read to the subjects by the experimenter. However, at the end of the instructions, the subjects were asked if they had any questions. Many of them

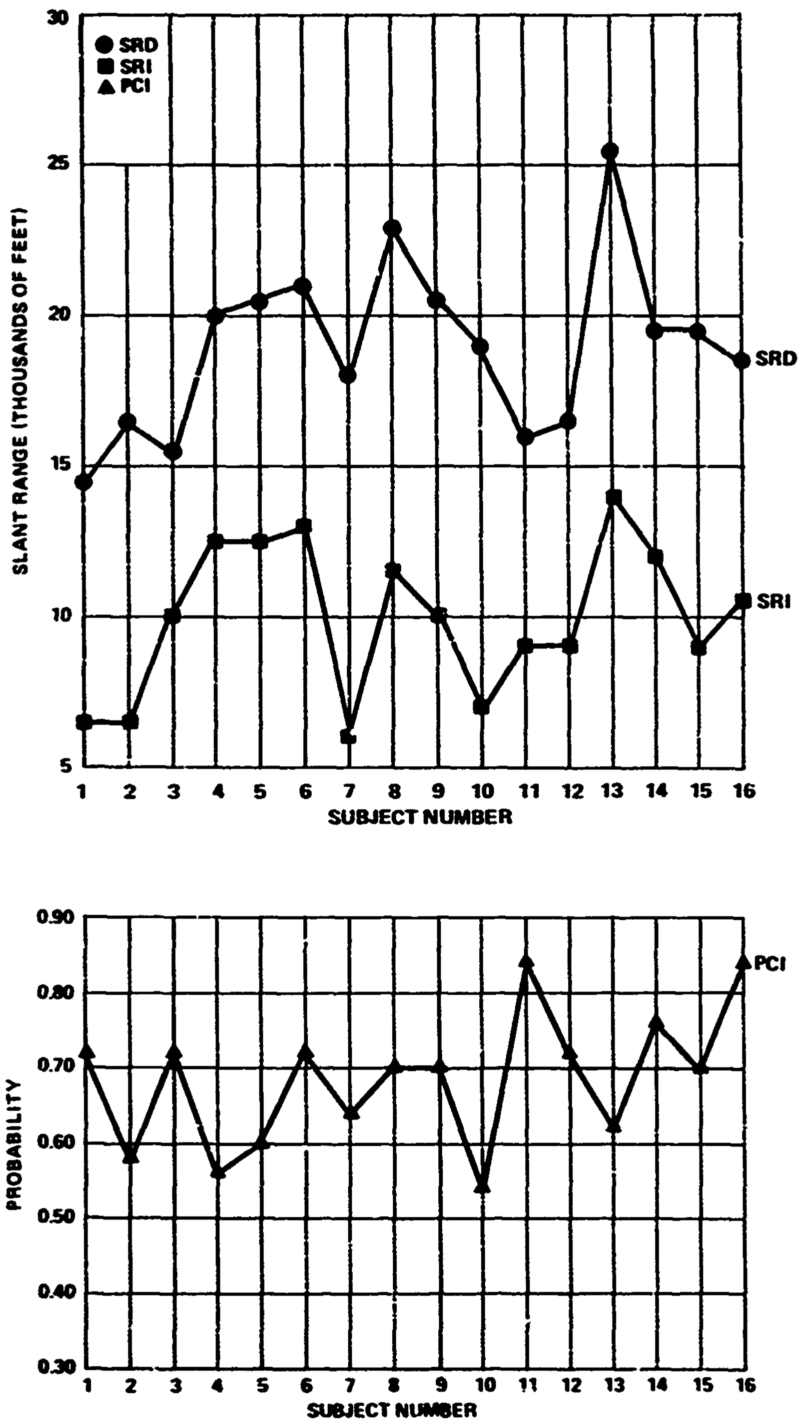


Figure 5. Subject Differences in SRD, SRI, and PCI.

did, and it is possible that the answers to these questions became more helpful as the experiment progressed and the experimenter gained more experience. Subjects were provided feedback as to the correctness of their target identification choice immediately after the end of each run. Spurious comments by the experimenter at this time also could have affected performance. Finally, subjects normally do vary considerably in their performance in studies of this type, and it is possible that the later subjects were simply inately better at these tasks than the earlier subjects.

Targets

Target differences for SRD, SRI, and PCI criteria are displayed in figure 6. The targets are presented in order of decreasing perspective area. Two predictors of detection and identification performance, perspective target area (PTA) and perspective target diagonal (PTD) are also shown in figure 6. PTA is the area which results when three-dimensional targets are reduced to two dimensions on TV. The longest diagonal line which can be drawn across the target on the TV display is the PTD. With all other factors held constant and provided visibility is unlimited, target detection slant ranges should be linearly related to perspective target area except for horizontally elongated targets, based on visual perceptual mechanisms. Perceptive target diagonal is also included here as a predictor because in a previous study (Bruns et al, 1970) (reference 3) PTD expressed as an angular measure at the eye of the observer was a better predictor of target identification performance than was PTA expressed in angular units. Table 10 contains the intercorrelations among PTD, PTA, and the response criteria.

It is evident from table 10, first, that PTD and PTA are highly correlated and second that PTD correlates higher with all three response criteria than does PTA. PTD and PTA are highly correlated because the targets used in this study are farily compact. If a combination of compact and greatly elongated targets had been used, the PTD-PTA correlation would have been much lower. Although PTD is a slightly better predictor of SRD, SRI, and PCI performance than is PTA, it can be demonstrated that at some point PTA will become a better predictor than PTD as targets become increasingly elongated. If target area were held constant while PTD increased, a point would be reached where even detection would be impossible because of insufficient target height. In this case, PTD would be negatively correlated with detection performance, and PTA would have 0 correlation with detection performance.

The correlations obtained in table 11 can be tested for their ability to account for target variance for each of the three criteria. Since PTD has the highest correlation with all three performance measures in this study, it will be tested using an F-test. An F-ratio is obtained by multiplying the sums of squares for targets for a criterion (e.g., SRD from table 5) by the square of the correlation coefficient shown in table 11 for PTD-SRD. This term is divided by the appropriate degrees of freedom to obtain a mean square which is then divided by the error mean square from the same analysis. The resulting F-ratio indicates whether the variance accounted for by the predictor, PTD, differed significantly from chance. An F-test can also be performed after the above test has been made to determine if the remaining variance not accounted for by the predictor differs significantly from chance. The results of these operations are shown in table 11.

It is evident from table 11 that PTD is a significant predictor of performance on all three criteria and that it accounts for most of the variance of SRD and SRI. In fact, PTD predicts SRI to the extent that all remaining SRI variance is probably due to chance. Although PTD

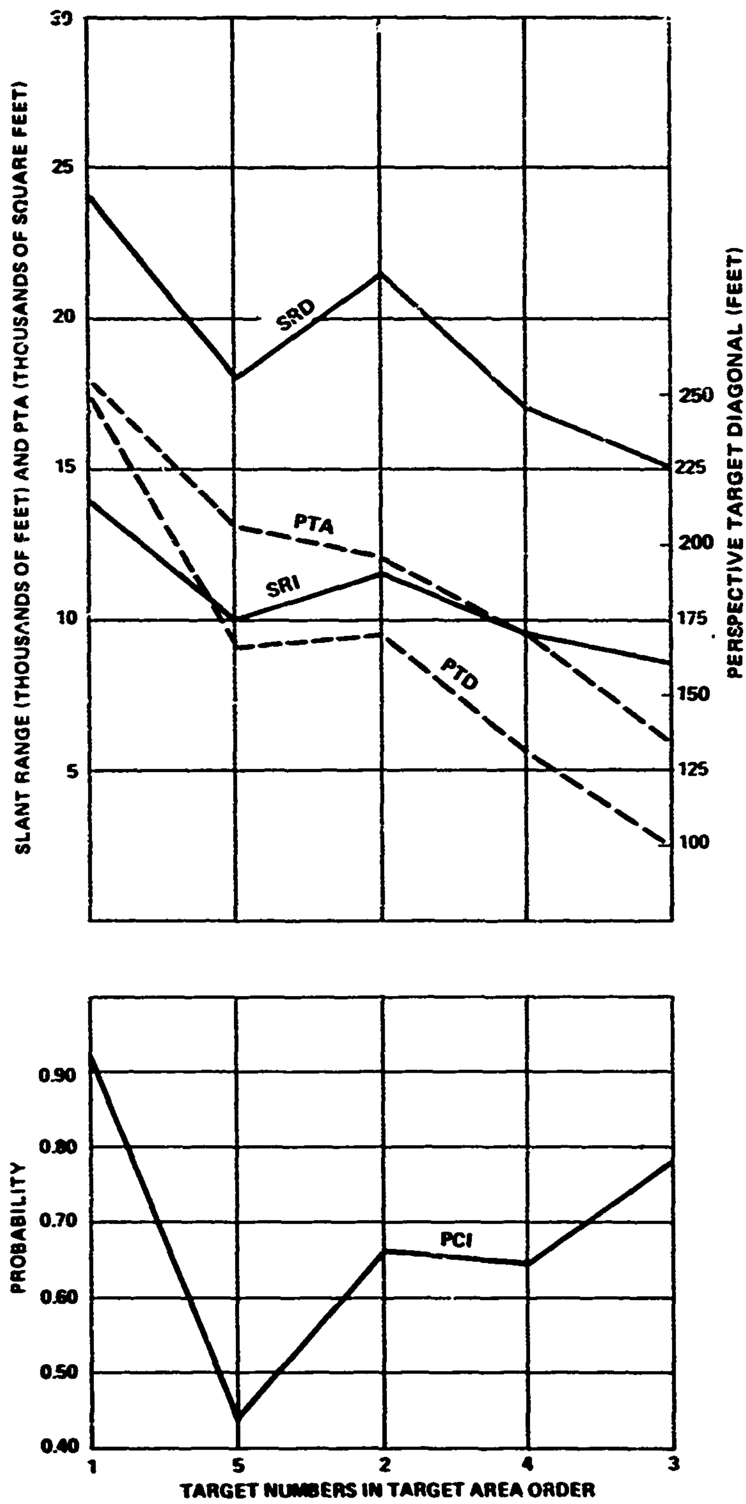


Figure 6. Target Differences in SRD, SRI, and PCI and Comparison With Predictors PTA and PTD.

Table 10. Intercorrelations Among PTD, PTA, and the Response Criteria

	PTD	PTA	SRD	SRI	PCI
PTD	1.000	0.993	0.937	0.982	0.335
PTA		1.000	0.897	0.951	0.213
SRD			1.000	0.974	0.409
SRI				1.000	0.449
PCI					1.000

Table 11. Analysis of Target Variance Accounted for by PTD and Target Variance Accounted for by All Other Factors

PTD	SS*	r^2	SS (r^2)	df	MS	EMS*	F	p
SRD	10.12	0.878	8.89	1	8.89	0.087	102.2	<0.005
SRI	8.80	0.964	8.48	1	8.48	0.102	83.1	<0.005
PCI	10.88	0.126	1.37	1	1.37	0.133	10.3	<0.005
Residuals			**SS-SS (r^2)**	**df**	**MS**	**EMS**	**F**	**p**
SRD			1.23	3	0.410	0.087	4.71	<0.005
SRI			0.32	3	0.107	0.102	1.05	NS
PCI			9.51	3	3.170	0.133	23.83	<0.005

*Sum of squares and error mean square data from tables 5, 6, and 7.

is statistically significant in predicting PCI, the amount of variance accounted for is fairly small. This implies that other factors are largely responsible for variation in PCI. Some insight as to what these factors are can be gained from table 12 which shows how often each target was correctly identified and what targets each target was confused with when incorrectly identified.

Table 12. Confusion Matrix of Target Identification

Correct Response	Subject Response Number of Times Identified as Target: 1	2	3	4	5	Total Error	PCI
1	116	11	0	0	1	12	0.87
2	43	84	1	0	0	44	0.66
3	1	13	100	13	1	28	0.78
4	1	6	27	84	10	44	0.66
5	1	3	4	64	56	72	0.44
						Total 200	Average 0.688

The data in table 12 indicate that there were substantial differences in the difficulty of identifying the various targets. Part of the differences is probably caused by the dissimilarity in apparent size intervals. A comparison of apparent size data from table 1 reveals that target

1 appears 84 feet longer than target 2 whereas target 5 appears only 41 feet higher than target 4. However, this explanation fails to account for the fact that there is almost no reciprocity of target identification errors (numbers connected by dotted lines in table 12). Target 5, for example, was identified as target 4 sixty-four times, but target 4 was identified as target 5 only ten times. Although there is no experimental basis for explaining this result, two possible causes have occurred to the experimenters. First, minor differences in target coloration could have occurred as a result of handling the targets after the runs were video-taped and before the briefing photographs were taken. Second, minor variations could have occurred to the distance, altitude, and downlook of the TV camera used to scan the targets. Either of these factors could result in individual targets appearing proportionately larger or smaller in the briefing photographs than they appear in the video tapes.

Contrast

The estimated contrast effects for the SRD, SRI, and PCI criteria are shown in figure 7. Contrast was significant for each of the three criteria ($p < 0.005$). Increased target contrast results in greater slant range at target detection and identification and improved target identification accuracy. A comparison of the contrast data in table 8 with the results shown in figure 7 emphasizes the fact that contrast is proportionately a better predictor of SRI than PCI and an even better predictor of SRD than either SRI or PCI.

The linear nature of the graphs in figure 7 is due to the use of only linear terms in the model. However, the use of linear terms resulted in an "unbiased" estimate of the linear component of the general curves underlying the contrast effect. Although an "ogive" curve might reflect the underlying relationship better, it was concluded from examining previous studies that the contrast effect is effectively linear over the range of contrast examined. The reader is cautioned, however, not to extrapolate the data beyond the contrast regions shown in figure 7.

Scan Line Orientation

The effects of scan line orientation are depicted in figure 8. SLO was found significant for the SRD criterion and insignificant for the SRI and PCI criteria. However, the fact that the differences are all in the same direction for all three criteria provides supportive evidence for the superiority of vertical compared to horizontal scan line orientation. Furthermore, although the magnitude of improvement in detection performance is modest (2,000 feet or about 11 percent), it represents a factor which is under the system designer's control and a change which could be made in future systems at small cost. Inherent target size and contrast, by comparison, are fixed, and increasing apparent target size and contrast requires expensive system modifications involving other tradeoffs as well.

Display Viewing Angle

The DVA (display viewing angle) effect was not significant for any of the three criteria. It was indicated in the introduction that in a previous study (Bruns et al. 1970) (reference 3) DVA was also found not to affect the range of target identification, but that DVA might be important for target detection in terms of eye fixations. Although a true unaided target detection task was included in the experimental design (phases 1 and 2), the failure of the simulated target attacks to proceed closer to the target location in phase 2 resulted in over 99 percent of the target identifications not occurring until the subjects were told that the target was

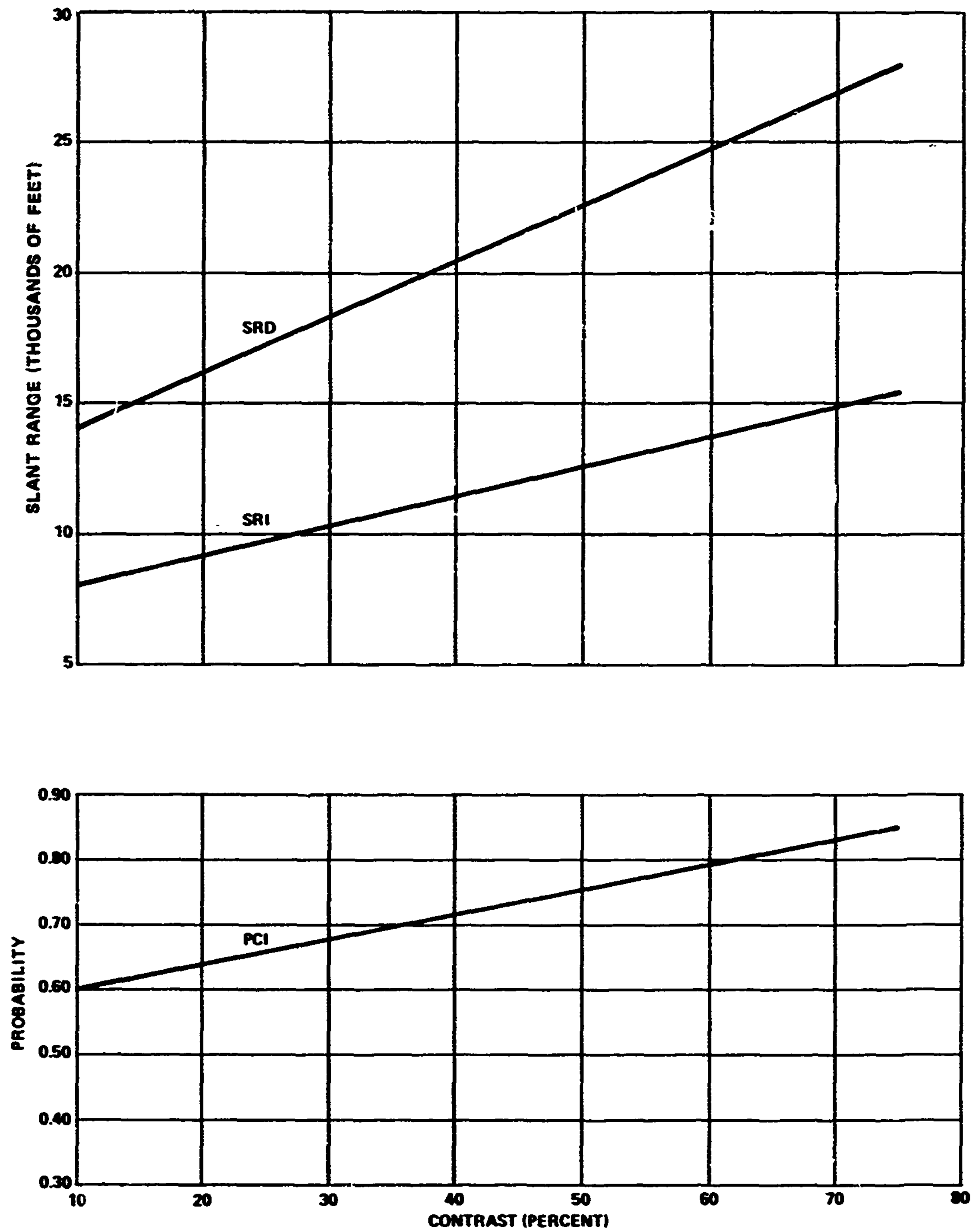


Figure 7. Estimated Contrast Effects on SRD, SRI, and PCI.

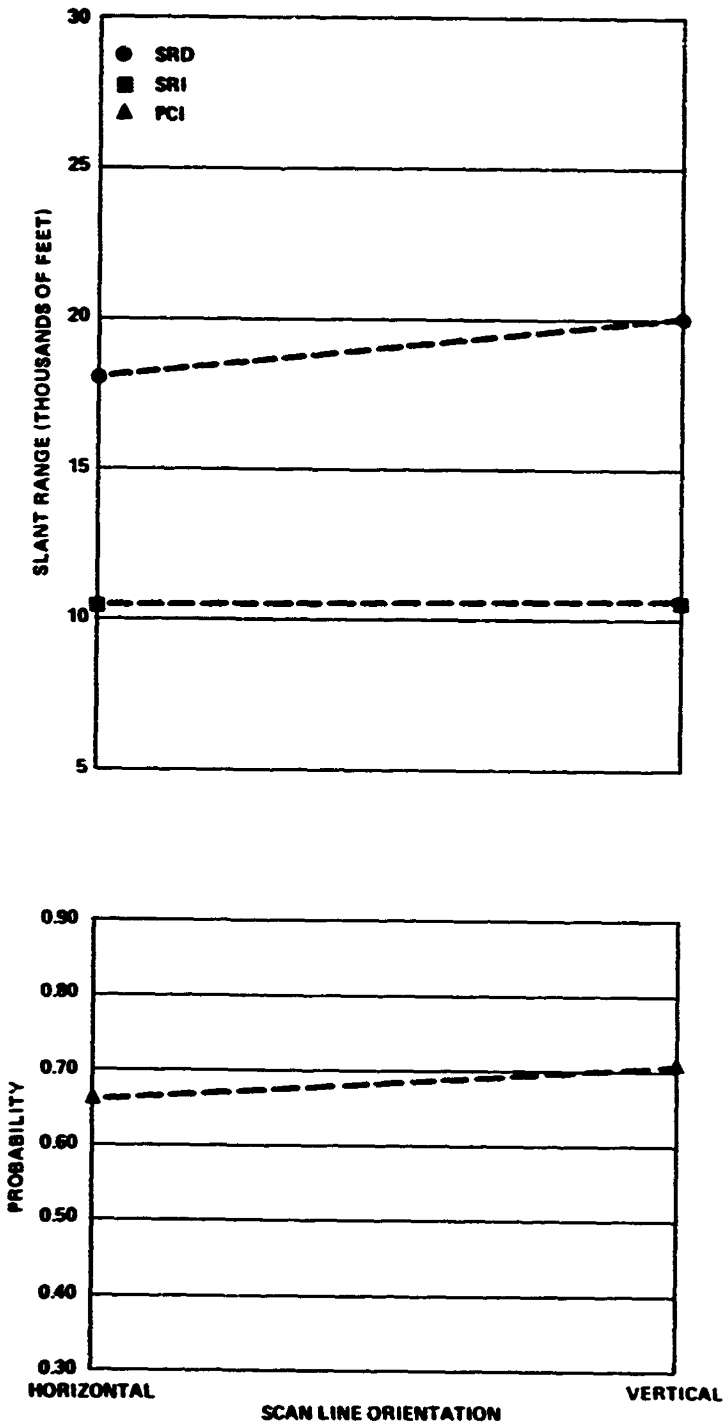


Figure 8. Scan Line Orientation Differences in SRD, SRI, and PCI.

within a 1-inch square at the center of the display (phase 3). Under these conditions very little shifting of eye-fixation points was necessary, and it is felt that a true test of the relationship of DVA to unaided target detection was not accomplished in this study. One factor which suggests that DVA might be important for target detection is that of the three criteria, SRD, SRI, and PCI, DVA comes closest to statistical significance with SRD ($0.10>p>0.05$). Figure 9 contains the DVA regression weights for SRD. These weights are slant range in feet relative to DVA 18 degrees which is set to 0 in the analysis.

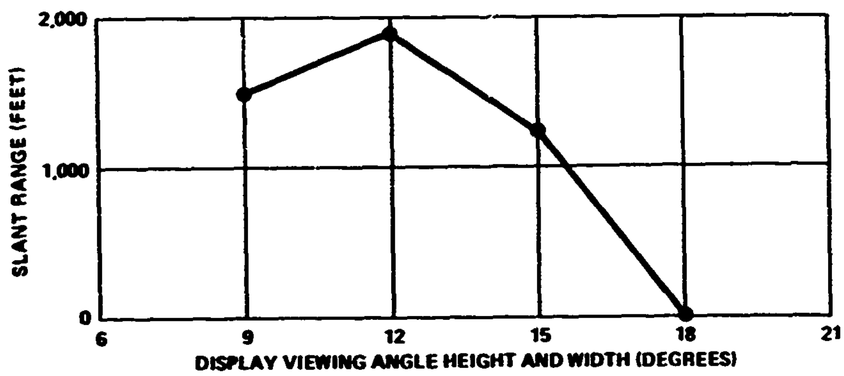


Figure 9. Change in SRD as DVA Changes.

Maximum detection range occurs when DVA is 12 degrees, and performance tends to degrade when moving toward the extremes of the DVAs tested. These results are not conclusive because of the substantial possibility that they could have occurred by chance, but they strongly suggest that further research should be undertaken on this parameter.

Raster Scan Lines and Image Subtense

In the introduction to this report it was indicated that several researchers had found that two conditions had to be met before an object could be identified on television. An object must be a minimal size in terms of angular subtense at the eye of the viewer, and a minimal number of television raster scan lines must cross the object. Calculations based upon the data contained in figure 9 indicated that average target angular subtense for target detection is at a minimum when the DVA is 9 degrees. Although average physical target size on the monitors is slightly smaller with a 12-degree DVA, the fact that the observer is closer to the display results in a larger target angular subtense than with a 9-degree DVA. Target angular subtense is also minimal for target identification when the DVA is 9 degrees. Table 13 contains the average target angular subtense and number of raster scan lines crossing the target for both target detection and identification when a 9-degree DVA is used.

The data in table 13 indicate that substantial differences exist among targets in terms of the average number of scan lines crossing the target and the target angular subtense required for both detection and identification. Two trends are evident. First, the greater the elongation of

Table 13. Average Target Angular Subtense and Number of Raster Scan Lines Crossing Targets for Target Detection and Target Identification When the DVA Height and Width is 9 Degrees

Detection

Target	Perspective Size (Feet)	Aspect Ratio	Scan Lines	Scan Line Area	Target Angular Subtense (Minutes of Arc)	TAS Area (Square Minutes of Arc)
1	250 x 73	3.42	26.2 x 7.47	196	36.5 x 10.3	376
2	166 x 73	2.27	18.8 x 8.04	151	26.2 x 11.4	299
3	83 x 73	1.14	11.2 x 9.59	107	15.5 x 13.4	208
4	115 x 83	1.39	14.7 x 10.6	156	20.7 x 14.8	306
5	156 x 83	1.83	19.3 x 10.4	201	26.8 x 14.5	389
Average	154 x 77	2.00	18.0 x 9.22	162	25.1 x 12.8	316

Identification

Target	Scan Lines	Scan Line Area	Target Angular Subtense (Minutes of Arc)	TAS Area (Square Minutes of Arc)
1	34.4 x 9.85	339	48.2 x 13.8	665
2	22.0 x 9.42	207	30.7 x 13.1	402
3	13.0 x 11.2	146	18.2 x 15.5	282
4	17.8 x 12.8	228	24.8 x 17.9	444
5	23.3 x 12.6	294	32.8 x 17.5	574
Average	22.1 x 11.2	243	30.9 x 15.6	473

the target either horizontally or vertically, the larger it must be to be both detected and identified. Second, targets which are vertically oriented on the monitor (targets 4 and 5) are larger when detected and identified than those which are horizontally orientated (targets 1, 2, and 3). Both of these findings are consistent with visual perceptual theory although the magnitude of difference is greater than predicted. Research by Kristofferson (1954, 1957) (references 17 and 18) discussed by Dember (1965) (reference 19) has shown that the greater the compactnes of an object, the more easily it is detected and research has found that human visual acuity is better horizontally than vertically. Another factor making targets 4 and 5 more difficult to identify than expected is the fact that both their physical size and aspect ratios are closer to each other than targets 1, 2, and 3.

Another interesting pheonoma is evident when the scan line data in table 13 are combined with the slant range data of tables 5 and 6. Since only one raster size and only one scan line rate were used in the study, the number of scan lines crossing the target is linearly related to the slant range data for each scan line orientation. If the number of scan lines crossing the target were *the* critical parameter, it would be expected that when the scan line orientation is perpendicular to the target length, detection and identification should occur sooner than when scan line orientation is paralleled to target length. If this happened, the T*SLO interaction should be significant in the variance partitioning. The data in table 6 reveal virtually no interaction occurred for target identification, nor was SLO a significant main effect. However, for target detection SLO was a statistically significant main effect and T*SLO just missed being statistically significant (0.10>p>0.05). This means that there is a substantial probability that a target-scan line orientation interaction exists although the proportion of variance accounted for is less than 1 percent. Further research is necessary before a definitive statement can be made about the extent of the interaction between target orientation and scan line orientation.

The data in table 13 indicate that it is difficult to generalize concerning a single average target size or number of scan lines crossing the target for either target detection or target identification. Furthermore, the average values obtained are probably task dependent—particularly for target identification. In most comparable research studies, targets usually can be aligned so that they are viewed broadside. Then, both the number of scan lines and target angular subtense are expressed relative to target height on the monitor. If the overall target detection results of this study are expressed in these terms, about 9.2 scan lines across the perspective target height dimension combined with a perspective target height angular subtense of about 12.8 minutes of arc are the minimal conditions necessary for a 50 percent cumulative probability of correct target detection. If a normal distribution of detection responses is assumed, the SRD standard deviation of 8,849 feet can be used to calculate any other cumulative probability of target detection. This assumption has been checked by the authors for both actual and simulated detection data and has been generally found to be true. Under this assumption 90 percent of the targets in the experiment would have been detected when 14.7 scan lines crossed the target with a corresponding target angular subtense of 20.4 minutes of arc. Since DVA was not significant in the SRD analysis, moving closer to the TV display and thereby increasing the target angular subtense will not appreciably change the target detection probability.

DISCUSSION

One question of immediate concern to the author is "How generalizable are the results of this study to an operational environment?" It is felt that the findings of the relative importance of the variables investigated are generalizable when the real world tasks are similar. Of the three response criteria used, the SRD task is most nearly like that encountered under certain operational conditions. These conditions are (1) minimal target surround cues, (2) similar equipment characteristics, (3) equivalent environmental conditions, (4) similar target characteristics, and (5) the observer must know where on his display the target is likely to appear. If substantial differences exist on these variables between the simulation and the operational situation, the range at which target detection occurs will change. The relative importance of the independent variables investigated in this study hopefully would not change nearly as much. For example, in an operational situation where the target is a dam on a river, the widening of the river behind the dam would enable the dam to be detected at a much greater slant range than would be predicted based solely on the size and contrast of the dam. However, when compared with the detection range of other dams on rivers, knowing the size and contrast of each should permit a good comparative SRD prediction.

The target identification tasks used in this study are not as similar to the operational situation as the detection task. The PCI results were almost completely a function of how close the target sizes and shapes were to each other. The identification task basically was one of height-to-width ratio comparisons—not usually the task required of an airborne observer. Generally, the airborne observer's identification task involves both the detection of a number of "features" of an object and a comparison of those features with either a photograph or a "mental image" of the object. When the observer has satisfied an internal criterion of certainty that the object being viewed is what he has been searching for, he commits himself by taking appropriate action. Hence, the identification task involves a number of feature detection tasks. This suggests that the results for the SRD criteria also have relevance for the identification task. For these reasons, the majority of the recommendations will be based upon conclusions drawn from the SRD results.

CONCLUSIONS AND RECOMMENDATIONS

Target contrast was the most important variable affecting target detection and was the second most important, after subjects, affecting target identification. The actual contrast of the target with its surroundings is not under the system designer's control. However, the apparent contrast between a target and its background can be increased by using contrast enhancement techniques which selectively amplify certain portions of the video signal. Because of the great importance of contrast to target detection and identification, developmental work in this area should be accelerated.

Although scan line orientation is not nearly as important a variable as contrast, a switch to vertical scan in future systems could be made with little additional cost. Before such a change is unqualifiedly recommended; however, further research should be performed to verify the results of this study. Future work under this AIRTASK will test the generality of the scan line orientation results discovered in this study.

As noted earlier, display viewing angle was not significant for any of the three criteria although it came closest for SRD ($0.10 > p > 0.05$). Future research will be designed to include a target detection task involving search across the entire display. The present findings suggest, although they do not prove, that a 12-degree display viewing angle height may be optimum.

In summary, based on the results of this study, it is recommended that further research focus on (1) techniques for contrast image enhancement, (2) verification of the superiority of vertical versus horizontal scan line orientation, and (3) delineation of the effects of display viewing angle upon a target detection task requiring search across the entire television display.

REFERENCES

1. Zachary, R. A. "Low Light Level Television as an Aid to Night-Time Air Rescue," in NAECON '67; Proceedings of the Nineteenth Annual National Aerospace Electronics Conference, Dayton, Ohio, May 15-17, 1967. UNCLASSIFIED

2. Armed Forces - NRC Committee on Vision. Visual Factors Relating to Optically-Controlled Indirect-Fire Point Target Weapons (U), by J. F. Gebhard, Editor. Report of Working Group 30, National Academy of Sciences. Jul 1968. CONFIDENTIAL.

3. Naval Missile Center. Dynamic Target Identification on Television as a Function of Display Size, Viewing Distance, and Target Motion Rate, by R. A. Bruns, LCDR R. J. Wherry, Jr., and A. C. Bittner, Jr. Point Mugu, Calif., Naval Missile Center, Nov 1970 (TP-70-60). UNCLASSIFIED.

4. Enoch, J. M., "Effect of the Size of a Complex Display Upon Visual Search," OPTICAL SOC AM J, Vol. 49 (1959), pp. 280-286

5. Shurtleff, D., et al. Studies of Display Symbol Legibility. Part IX, The Effects of Resolution, Size and Viewing Angle of Legibility. Bedford, Mass., The Mitre Corporation, May 1966. (ESD-TR-65-411).

6. Baker, C. A. and Nicholson, R. M. "Raster Scan Parameters and Target Identification," in NAECON '67; Proceedings of the Nineteenth Annual National Aerospace Electronics Conference, Dayton, Ohio May 15-17, 1967. UNCLASSIFIED.

7. Hemingway, J. C. and R. A. Erickson. "Relative Effects of Raster Scan Lines and Image Subtense on Symbol Legibility on Television," HUMAN FACTORS, Vol. 11 (1969), pp. 331-338.

8. Shurtleff, D. A. "Studies in Television Legibility - A Review of the Literature," INFORMATION DISPLAY, Jan/Feb 1967.

9. Naval Weapons Center. Image Identification on Television, by R. A. Erickson and J. C. Hemingway. China Lake, Calif., NWC, Sep 1970. (NWC-TP-5025) UNCLASSIFIED.

10. ———. Effects of Raster Scan Lines and Image Subtense on Observer Performance in Television, by J. C. Hemingway and R. A. Erickson. China Lake, Calif., NWC, Apr 1968. (NWC-IDP-2883) UNCLASSIFIED.

11. Bennett, C. A., S. H. Winterstein, R. E. Kent. "Image Quality and Target Recognition," HUMAN FACTORS, Feb 1967. Vol. 9, No. 1, pp. 5-32.

12. Naval Weapons Center. "Evaluation of a High Resolution TV System," by R. A. Erickson and J. C. Hemingway. China Lake, Calif., NWC, Aug 1967. (NOTS [illegible]771)

13. Shurtleff, D. A. and Owen D.. "Studies of Display Symbol Legibility: The Legibility of Leroy Symbols on a 945 Line and 525 Line Television System." The Mitre Corporation, May 1966. (ESD-TR-65-137)

14. Cochran, W. G. and G. M. Cox. Experimental Design, 2nd ed. New York, Wiley & Sons, 1957.

15. Dixon, W. J., ed. BMD Biomedical Computer Programs. University of California Press, 1965.

16. Overall, J. E. and D. K. Spiegel, "Concerning Least Squares Analysis of Experimental Data," PSYCHOLOGICAL BUL, Vol. 72 (1969), pp. 311-323.

17. Kristofferson, A. B. Foveal Intensity Discrimination as a Function of Area and Shape. Unpublished doctoral dissertation, Univ. of Michigan.

18. Kristrofferson, A. B. Visual Detection as Influenced by Target Form. In Wulfek, J. W. and Taylor, J. A. (eds.) FORM DISCRIMINATION, National Academy of Sciences-National Research Council, Washington, D. C., 1957, Pub. 561.

19. Dember, W. N., Psychology of Perception. New York, Holt, Rinehart, and Winston, 1965.

APPENDIX

INSTRUCTIONS TO SUBJECTS

"You are about to participate in an experiment designed tc termine the effects of target contrast, display viewing distance, and television raster scan line o.ientation upon your ability to detect and identify buildings on the ground as seen from an attacking aircraft or missile's video tape flight record.

"Please be seated in this chair and adjust its height so that your forehead will rest against the padded bar when you are viewing the display. Please rest your forehead against the padded bar during each target attack and view the display with both eyes. *(Demonstrate)* Your head should be approximately centered on the padded bar. When not viewing the display, you may sit back in your chair.

"On the console below the display are five photographs, each containing a picture of a different rectangular building as it would appear close up from the air. All five photographs show the same background. This background is representative of the type of terrain wherein the buildings will be found, but it is not the exact background for any of the target placements.

"Your task is to search the imagery to be shown on the display to see if (1) you can detect any one of these five buildings, and (2) if you can identify which building it is that you have detected. When you have spotted an object that you believe is one of these buildings, place the tracking gate around the object and depress and release the pushbutton located on the lower left portion of the console. Then move the tracking gate off the display to the right. *(Demonstrate).*

"If you find that the object which you designated is not one of the five buildings in the photographs, resume your search for the building and repeat the target-marking process when you detect a building.

"As soon as you can identify which building you have detected, depress and release the pushbutton below the photograph of that building. Continue watching the display to verify that your identification is correct. If you decide that you have selected the wrong photograph, depress and release the pushbutton beneath the correct photograph.

"Each simulated target attack presentation is divided into three phases:

Phase 1. All attacks will begin from the same point in space with the aircraft hovering for 30 seconds at an altitude of 27,500 feet. The aircraft and camera will be inclined in a 30-degree dive and will be positioned so that the camera is pointed at approximately the center of the terrain to be searched.

Phase 2. The aircraft will then proceed toward the center of the terrain area for 30 seconds at about 350 knots. Only one building will be on the terrain at a time and this building will be within the field of view at all times. No other man-made objects will be present on the terrain.

Phase 3. After the above 60 seconds have elapsed, the aircraft will be instantly repositioned so that the television camera is boresighted on the target location. The target will now appear within 1/2 inch of the dot marking the center of the display. The target attack will restart from 27,500 feet and will continue until the aircraft reaches 2,750 feet.

"Repeat the target detection and identification process described above whether you have already done so or not. We will begin with five practice attacks. The duration of the experiment will be about 2 hours. Are there any questions?"